Demonstration of GaN/InGaN Light Emitting Diodes on (100) β-Ga_2O_3 Substrates by Metalorganic Chemical Vapour Deposition *

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The growth and fabrication of GaN/InGaN multiple quantum well (MQW) light emitting diodes (LEDs) on (100) β-Ga_2O_3 single crystal substrates by metal-organic chemical vapour deposition (MOCVD) technique are reported. x-ray diffraction (XRD) $\theta - 2\theta$ scan spectroscopy is carried out on the GaN buffer layer grown on a (100) β-Ga_2O_3 substrate. The spectrum presents several sharp peaks corresponding to the (100) β-Ga_2O_3 and (004) GaN. High-quality (0002) GaN material is obtained. The emission characteristics of the GaN/InGaN MQW LED are measurement. The first green LED on β-Ga_2O_3 with vertical current injection is demonstrated.

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Wurtzite GaN and related materials are widely used for ultraviolet to green and blue light emitting diodes and lasers. Most of these materials and devices are grown on the substrate of sapphire. Unfortunately, the large lattice and thermal expansion mismatch between GaN and the sapphire.[1] The insulating character of the sapphire affects its use in the device fabrication. Due to the opacity of the sapphire in the blue wavelength region, the optical losses have been taken into account for the design of LED. The search for alternative substrates has been pursued intensively.[2,3]

It is well known that β-Ga_2O_3 is a kind of transparent conductors and has n-type conductivity. It has the unique transparency from the visible into the UV region. It exhibits the largest band gap among them, $E_g = 4.8$ eV (260 nm). This is an important property for the future generations of optoelectronic devices operating at shorter wavelengths.[3] Thus, β-Ga_2O_3 is a new substrate candidate for the growth of GaN related materials and devices. The device performance of LEDs on β-Ga_2O_3 single crystal substrates still has been reported little. In this Letter, we report the growth and fabrication of GaN/InGaN MQW LED on (100) β-Ga_2O_3 single crystal substrates by MOCVD technique.

The transparent β-Ga_2O_3 substrates were prepared by the floating zone technique with Ga_2O_3 (5N) powder.[4] Here (100) surfaces were used for GaN and GaN/InGaN MQW LED deposited. The pressure100 Torr was reached in the LP-MOCVD system. Trimethy gallium (TMG), trimethy indium (TMI) and NH_3 were used as the source gases. SiH_4 and Cp_2Mg were used as the dopant sources. The three-step method was employed, i.e. firstly a low temperature GaN buffer layer was deposited at 550°C, subsequently a high temperature GaN layer of 1.2 μm thickness was grown at 1050°C and then the GaN/InGaN MQW LED structure was deposited at 850°C. Finally the p-type GaN layer is deposited at 1050°C. Several GaN/InGaN multiple quantum wells were formed in the LED structure. The structures of the LED are shown in Fig. 1. To utilize the conductive nature of the β-Ga_2O_3 substrate, the GaN layers were n-type doped with Si by the flow of SiH_4 as source gas.

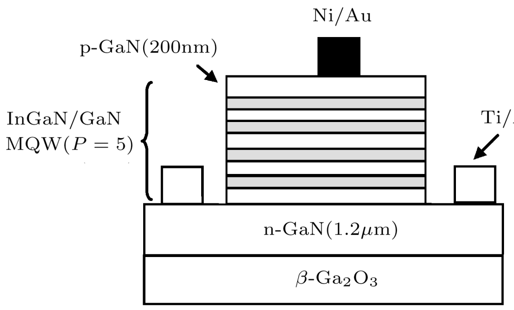

Fig. 1. Structures of the LEDs grown on transparent β-Ga_2O_3 substrate.

Samples were characterized by x-ray diffraction (XRD), PL and EL. For the PL measurements, the He-Cd laser ($\lambda = 325$ nm) was used as an excitation source. The spectral resolution was 1 cm^{-1}. The PL

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emission peak is at 529 nm. The green emission peak at 537 nm was obtained on EL measurements with 20 V voltages and 0.7 mA drive currents. All the measurements were carried out at room temperature.

The high resolution XRD was carried out on the GaN deposited wafer. The $\theta - 2\theta$ scan is shown in Fig. 2. The spectrum presents several sharp peaks corresponding to the (100) β-Ga_2O_3 substrate and the narrow and high intensity one corresponding to the deposited layer. Index of the latter indicated that the GaN peak corresponding to (0002) *c*-plane of GaN. We observed single crystal (0001) oriented hexagonal GaN growth on (100) β-Ga_2O_3 by MOCVD. No other peaks, such as (101) and (102), which could indicate the existence of not properly aligned domains within GaN layer, were detected. The x-ray rocking curve exhibited a full width at half maximum (FWHM) of 1800 arcsec for the GaN layer.

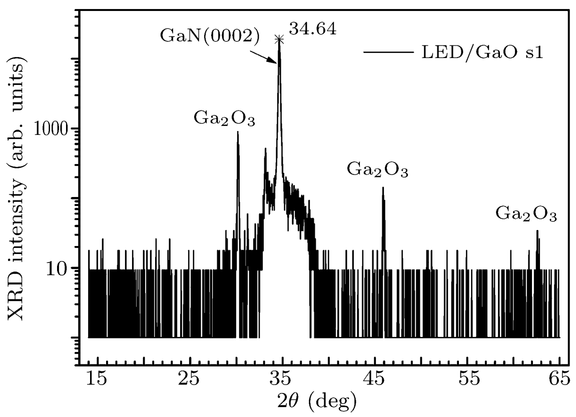

Fig. 2. X-ray $\theta - 2\theta$ scan of the GaN film grown on the β-Ga_2O_3 substrate.

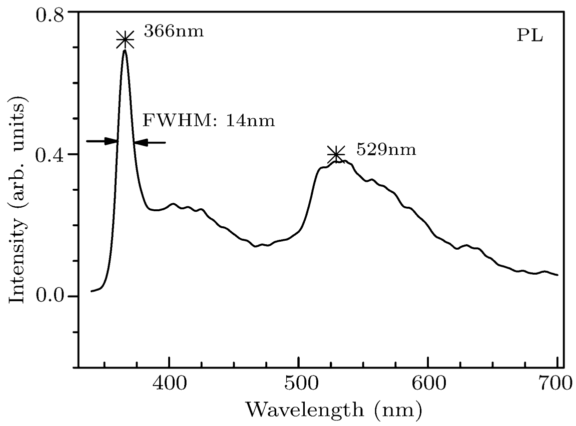

Fig. 3. PL emission characteristic of the LED film grown on the β-Ga_2O_3 substrate.

The PL emission characteristic of the LED film is illustrated in Fig. 3. The spectrum shows a narrow emission peaking at 366 nm, corresponding to the bandedge of wurtzite on GaN. This bandedge luminescence, with an FWHM of 14 nm, was dominant and only a relatively low deep level emission was observed. The broad emission peaking at 529 nm, corresponding to the green blue light emission. The FWHM of the luminescence is broad. This means that the growth conditions of the system need to be improved. Figure 4 shows the EL measurements and emission green blue light photograph of the LED. The green blue emission peak at 537 nm was also obtained on EL measurements with 20 V voltages and 0.7 mA drive currents. There are several other peaks near the indicated peak, located at 520 nm and 537 nm. These peaks come from the effect of the interference by interface or the blue shift of the localized states induced by alloy fluctuation in InGaN quantum wells.[5] This is the same as the PL emission peak broad at 529 nm. The electrical and other properties of the GaN and GaN/InGaN LED structure materials are for the future investigation. This result demonstrates the successful green blue light LED fabrication on the β-Ga_2O_3 substrate. The optimization of the growth conditions and the materials parameters are in progress to further improve the performance of LEDs.

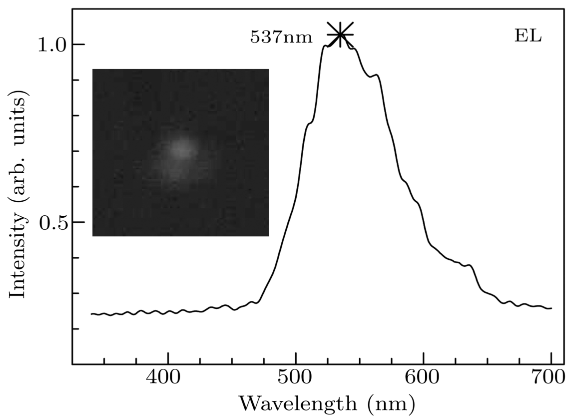

Fig. 4. EL measurements and emission green light photograph of the LED.

In summary, a GaN/InGaN MQW LED has been grown on the near-UV transparency β-Ga_2O_3 substrate by MOCVD technique. The n-type conductive GaN buffer layer is deposited under the LED structure on the substrate. The LED can successfully emit the green light after the vertical current injection. The PL emission peak is at 529 nm. The green blue emission peak at 537 nm is obtained on EL measurements with 20 V voltages and 0.7 mA drive currents. This result demonstrates the high potential of β-Ga_2O_3 as a new substrate with UV transparency and conductivity.

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